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16. ABSTRACT

The feasibility of using automatic fog detectors in a fog-hazard warning system was investigated. Three fog sensors were installed and evaluated on a comparative basis. Due to atypical meteorology, there was insufficient dense fog for adequate testing. Of the three instruments tested, only the Fog Visiometer supplied by Meterology Research, Incorporated showed promise.

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DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
TRANSPORTATION LABORATORY
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Interim Report
Trans. Lab.#657121

July 1973

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research project report titled:

DETECTORS FOR AUTOMATIC FOG-WARNING SIGNS

By

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Under the Supervision of
John B. Skog, P.E.

Very truly yours,

JOHN L. BEATON
Laboratory Director

Attachment

ACKNOWLEDGEMENT

The assistance of Mr. Bill Juergens of the Division of Highways Traffic Branch, who administered the contract, is appreciated. Also, the assistance of the District 10 Traffic Department, who prepared the test site and maintained the instruments, is acknowledged.

The cooperation of Lear Siegler, Inc., Meteorology Research, Inc., Kahl Scientific Instrument Corporation, and AeroVironment, Inc. in providing the automatic Instruments is appreciated.

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INTRODUCTION

Fog has been a persistent problem for both automotive and airborne traffic for many years. It can be a particularly serious hazard in many places in the State of California, especially where discrete pockets of very dense "radiation" fog form in the Central Valley. As a result, considerable thought and effort has been given to ideas and devices designed to improve traffic safety.

This report describes a preliminary evaluation of an automatic fog warning system that could be used to warn motorists of hazardous driving conditions due to reduced visibility in fog. The study was conducted by the Division of Highways, Transportation Laboratory in cooperation with the Division of Highways, Traffic Branch.

CONCLUSIONS

The lack of dense fog precluded the analysis of a statistical relationship between the estimated visibility and the parameters measured by the automatic fog sensors. Of the instruments examined in this study, it appears that the instrument supplied by Meteorology Research Incorporated has the greatest potential. It was not determined how well visibilities measured by the various instruments were related to visibilities on the highway.

A HIGHWAY FOG WARNING SYSTEM

Various state agencies have been interested in the fog-related highway accident problem for some time. Previously, studies were conducted by the Division of Highways Maintenance Branch to see if it is possible to improve visibility in fog by applying a dispersal agent[1]. Also, the Division of Highways Traffic Branch has studied the effect of changeable signs which displayed the safe driving speed[2]. The California Highway Patrol (CHP) has developed "Operation Fogbound" where the motorist is warned via commercial radio of hazardous driving conditions during periods of dense fog (November through February in the Stockton area). The CHP also leads groups of cars through the fog at a safe driving speed (the "Round Robin" part of Operation Fogbound). Their experience leads them to suggest the following definitions[3]:

Critical fog - visibilities of 200 feet or less.

Dangerous fog - visibilities of 200 feet to 500 feet.

Light fog - fog with a visibility greater than 500 feet.

A highway fog warning system should be composed of at least two warning signs and several automatic fog detectors. The warning signs should be activated when a drastic, dangerous reduction in visibility is encountered.

Fog Detector

Historically, automatic fog detectors have been developed for use at airports and at foggy waterways. They are not always directly suitable for use on the highway. For example, the minimum visibility of interest at airports is about 660 feet (1/8 mile) in increments of 660 feet (eighths of a mile). A highway fog detector should operate over a range of about 50 feet to 1000 feet, within an accuracy of $\pm$ 25 feet. A change in visibility of $\pm$ 25 feet would correspond to a change in safe driving speed of $\pm$ 3 miles per hour (on wet pavement) in the range of 30-60 mph[4]. Typically, the motorist finds himself in trouble when he encounters a rapid change in visibility within the fog. He is aware that he is in fog, but he must be warned of an abrupt and unexpected decrease in his safe driving speed. In order to locate these changes, several fog sensors are required. Ideally, a proper highway fog detector should be inexpensive enough so that several of the instruments could be deployed within a hazardous fog area.

A small, battery powered sensor which would look inconspicious to the motorist or pedestrian would not need the security of a chain link enclosure if it were built to look like part of an existing piece of roadway equipment such as a guard rail post. Several instruments could be connected by telephone lines and used to activate signs, alert the CHP of possible problem areas, etc.

All of the fog sensors evaluated in this study would require some type of security such as a chain link enclosure. With the exception of the Fog Visiometer, the instruments are fairly large and distracting to the motorist. Although not a requirement, the transmissometer and the AeroVironment Fog Monitor are too large and bulky to be used for any type of mobile operation, but the Fog Visiometer and the Videograph are compact enough to be so employed.

Warning Sign

The warning sign should be large enough so that it is easily visible under adverse conditions. It should probably be in the form of a sign bridge so that it straddles the traffic lanes. Activating flashing yellow lights when a warning message is displayed on the sign would draw motorist's attention to the sign. Having multiple messages on the sign is not really necessary for fog warnings, but may be of value when used in conjunction with another mission (warning of an accident or congestion ahead, for example).

The sign used to alert motorists of adverse driving conditions was provided by Display Technology Corporation of Cupertino, California. The lack of lead time for the study called for the installation of two signs from existing stock. The sign chosen was not sufficiently large to be adequately visible in adverse weather. The locations of the signs were dictated by the requirements of power, guardrail protection, proximity to sensors, and availability of telephone lines which were connected to one of the fog sensors. Although the sign seems large at close range, it does not stand out from its surroundings in either foggy or clear weather.

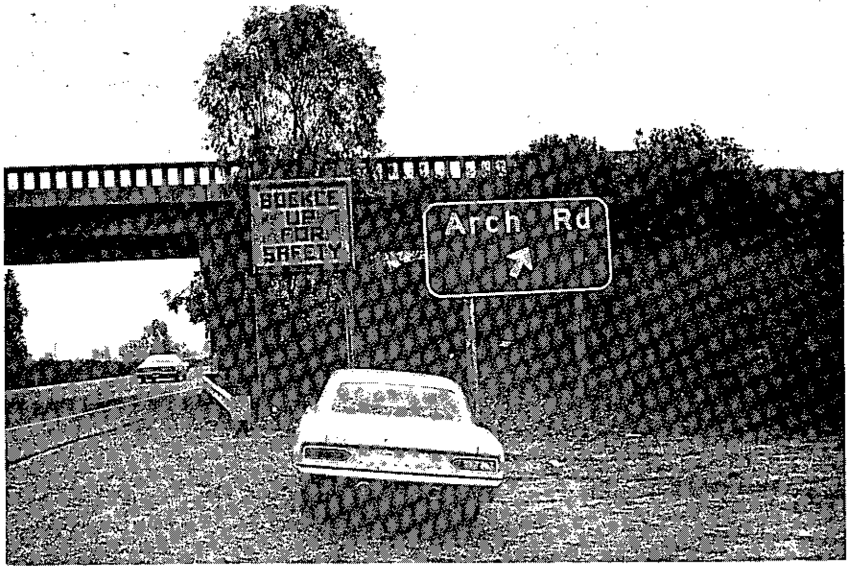


Figure 1

View of Warning Sign at Close Range

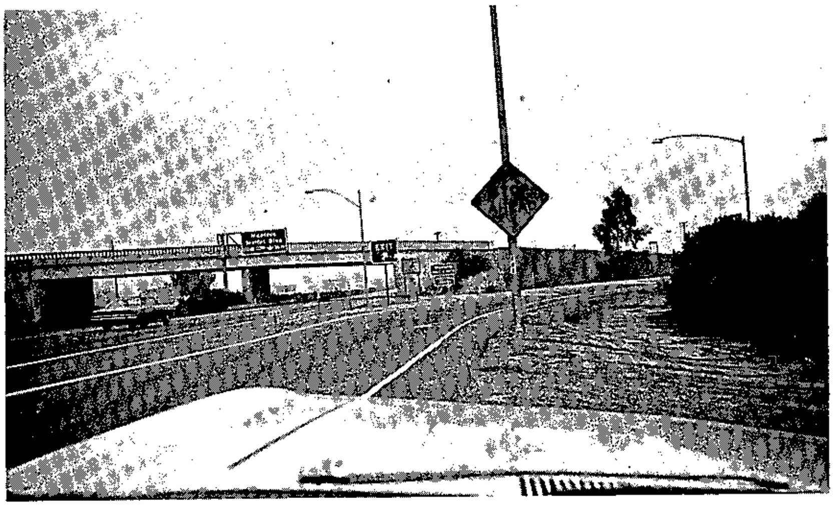


Figure 2

View of Warning Sign from Several Hundred Feet Distance

The message displayed on the signs during periods of adverse visibility is "Dense Fog Ahead". The words "dense" and "ahead" were 13 inches high while the word "fog" was 26 inches high. Since the letters of the words were not in the standard shapes or colors normally used on highways, standard graphs relating letter height to visibility could not be used.

The illumination of the sign was not proper for night time or fog conditions. Field alteration by the supplier led to a great improvement in visibility. During periods of heavy fog, however, the sign was still difficult to observe.

A control board was located at a nearby California Highway Patrol office. The CHP personnel had the option of overriding the automatic fog detectors. They could display fog warning messages and/or wreck ahead messages. They could also input the distance to the hazard.

TEST PROCEDURE

The fog sensors were located in a chain link enclosure about 50 feet from the highway, with the transmissometer placed parallel to the road. Since the enclosure is about 3 feet lower than the traveled way, the sensors were mounted at a 5 foot height in order to sample fog which was about 2 feet above the road.

The actual visibility was obtained by human observers. They approached a lighted tail light until it became visible. This distance was recorded, along with the time of the observation. The procedure was then repeated with an unlit object as the visibility target.

VISIBILITY TARGET

In dense fog with a relatively low background brightness (night time or a deep layer of fog during the day) the object which usually first becomes visible on the roadway is the automobile tail light. When the fog is shallow enough during daylight hours, solid, blocky objects first become visible. For these reasons, the intent of the study was to gather data using a dual definition of visibility:

1. Low background brightness:

   Visibility - "that distance at which a person can just discern a 'standard' tail light mounted at an average height above ground".

2. High background brightness:

   Visibility - "that distance at which a person can just discern a typical unlit object located adjacent to the highway" (such as a sign or a bridge).

The particular tail light that was chosen is considered to be of "typical" brightness and lighted area. It was mounted at a height of 29 inches above ground in a plywood test stand which was painted grey. The light was powered by a constant voltage power source at the design voltage of the bulb (14.0 volts). This tail light was obtained from a supply of lights evaluated for conformance to federal and state standards[5]. It is the opinion of the conformance testers that the brightness of the light and the lit cross sectional area of the light are typical.

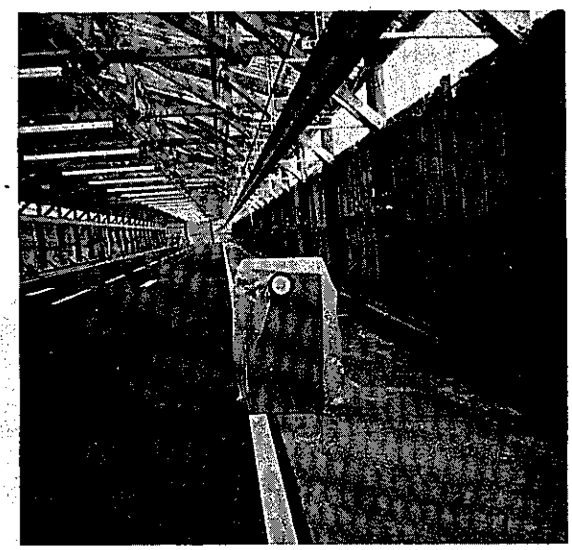


Figure 3

Tail Light Visibility Target

The second visibility target was an unlit highway sign located adjacent to the test site. The tail light was placed next to the sign. The observers slowly traversed the distance between themselves and the targets, moving towards the targets. When the first target became visible (always the tail light in the few observations that were made) the distance was noted. The observers then proceeded until the second target became visible. The observers were driving adjacent to the highway shoulder in an automobile at a low rate of speed at the time they made their observations.

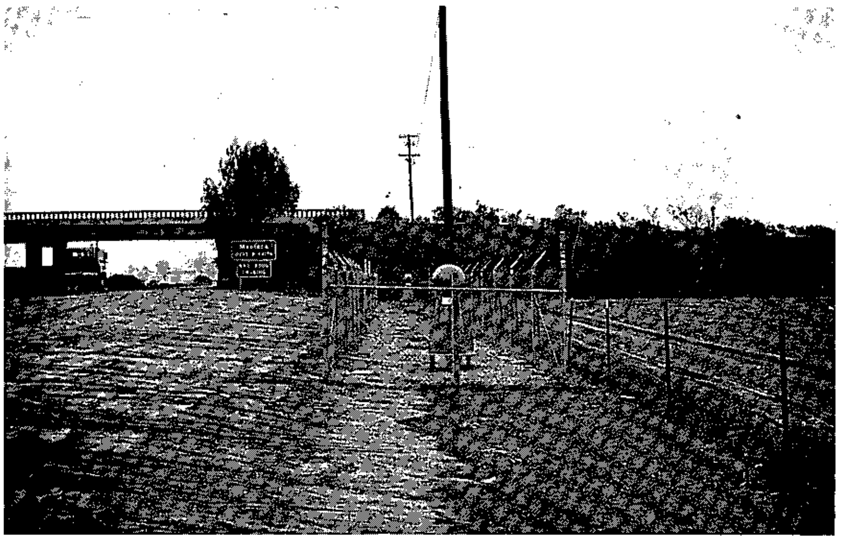


Figure 4

View of Unlit Visibility Target and General Layout of Site

INSTRUMENTS TESTED

Four fog sensors were installed for the test within a chain-link enclosure. Each fog sensor utilizes a different principle of operation. All measure intensity of light and use a mathematical model to estimate "meteorological visual range". None measure visibility directly. It was felt that if a significant correlation could be obtained between the data outputs of the fog sensors and the actual visibility as measured by a human observer, a statistical equation relating the two could be derived for each of the fog sensors. This would be possible only if the fog was more or less uniform (brightness, droplet size, etc.), and a different equation would be required if the fog parameters changed significantly.

The intent of the study was to travel to the site during periods of dense fog. At that time, the visibility would be estimated by observing both a "standard" tail light and a typical unlit object. The lack of dense fog at the test site kept us from obtaining data with which to generate the statistical relationships. It is felt that this relationship must be obtained before proceding with the planning, design, or operation of a fog-hazard warning system.

The four fog sensors and their individual characteristics are described below:

Lear Siegler, Inc - SM4 Transmissometer

This is a double path instrument with a sender-receiver at one location and a reflector 37 meters away. To insure precise optical alignment, large bases must be prepared with a rigid foundation.

Figure 5
SM4 Transmissometer

Special baffles are installed in both units in an attempt to keep the air adjacent to the lenses calm, preventing dust from obscuring the lenses. A beeper was provided in order to keep birds from setting up home in the optical path. The light from the sender is first modulated by a light chopper and then split into two beams. One beam is retained in the unit as a reference beam and the other beam is passed through the fog and back to the receiver. The ratio of the intensities of the two light beams is the transmission:

$$T\ (\%) = \frac{\text{Final intensity of sample beam}}{\text{Intensity of reference beam}} \times 100$$

The light chopper insures that only the light emitted by the sender is analyzed. Other light sources such as automobile lights and fixed roadway lights do not interfere.

The measured transmission, T, was recorded on a strip chart recorder equipped with a data pen and an event marker. During the test period it became apparent that the instrument was probably out of calibration. Attempts at recalibration were made by the instrument supplier. Although the output should have been 20 mA on a clear day, initially the output was about 18.5 mA and improved to about 19.5 mA after recalibration. However, a check of the strip chart recorder showed that the pen of the recorder consistently recorded about 10% lower than the actual transmission as indicated by the milliamp dial (20 mA = 100% transmission). Ten data pairs (milliamps and strip chart readings) were observed. A regression equation relating the data is:

$$T\ (\%) = 11.36 + 91.39 \times (\text{chart reading})$$

From the above equation any chart reading may be converted to the appropriate percent transmission. However, any transmission level below about 11% would be recorded as zero. Since 11% transmission corresponds to a visibility of about 315 feet, visibilities below this level were not recorded. Also, the instrument was set to turn on the warning sign when the <u>chart</u> read 10% transmission and off when the <u>chart</u> reading improved to 17%. It was thought that this corresponded to visibilities of about 310 feet and 440 feet respectively. Actually, the transmission levels were 20.5% and 27% and the corresponding visibilities about 500 feet and 600 feet. It is felt that these difficulties can be corrected by a revision in the electrical components between the milliamp dial output and the strip chart recorder.

The range of the instrument depends upon the path length selected for use. At the optimum path length (about 37 meters) the instrument's range is about .05 kilometers ($\pm$160 feet) to about 5 kilometers ($\pm$16,000 feet). At the low range, a small change in transmission causes a large change in visibility. This means that the transmissometer is not very precise at visibilities below about 300 feet or so.

The cost of purchasing and installing this instrument may preclude its widespread use for highway monitoring.

Meteorology Research, Inc. - Fog Visiometer

This is a short path instrument that measures light scattered forward, sideward, and backward from the main light beam. The sample area is about 1.4 feet in length. The flash lamp is inclined in the forward direction. Electronics are used to compensate for light scattered at angles approaching zero and 180 degrees from the original path of the light beam.

This instrument comes from the factory with instructions for obtaining the following visibilities[6]:

1. Runway Visibility (RVV) - the distance that an observer would observe visually in a given direction using as targets either dark objects against the horizon sky during daytime or unfocused lights of moderate intensity at night. RVV (meters) $= \frac{2.9}{b}$, where b = scattering coefficient as measured by the MRI Fog Visiometer.

2. Meteorological Range (L_{vd}) - the greatest distance at which a sufficiently large black object can be seen against the daytime horizon sky, assuming the eye is able to distinguish differences in contrast of 2%.

$$L_{vd} \text{ (meters)} = \frac{3.9}{b}$$, where b is as previously defined.

The relationship of either of these visibilities to the visibilities encountered on the highway is not clear. A graph relating highway visibility to the scattering coefficient was published in a report prepared by the California Division of Highways. The visibility target used in this case consisted of actual automobile tail lights[1]. It can be seen from Figure 6 that highway visibility (TSD) is significantly different than either L_{vd} or RVV.

The Fog Visiometer normally is set at a visibility range (L_{vd}) of 260 feet to 20,000 feet, but can be easily calibrated to read 100 feet to 10,000 feet. This second range can be halved or quartered to obtain readings down to 50 feet or 25 feet respectively. This would require the manufacturer to establish another calibration point but would greatly increase the usability of the instrument.

The Fog Visiometer seemed to operate properly once the installation was completed. It was not possible to obtain observations of highway visibility while the Fog Visiometer was installed due to a lack of dense fog at the test site.

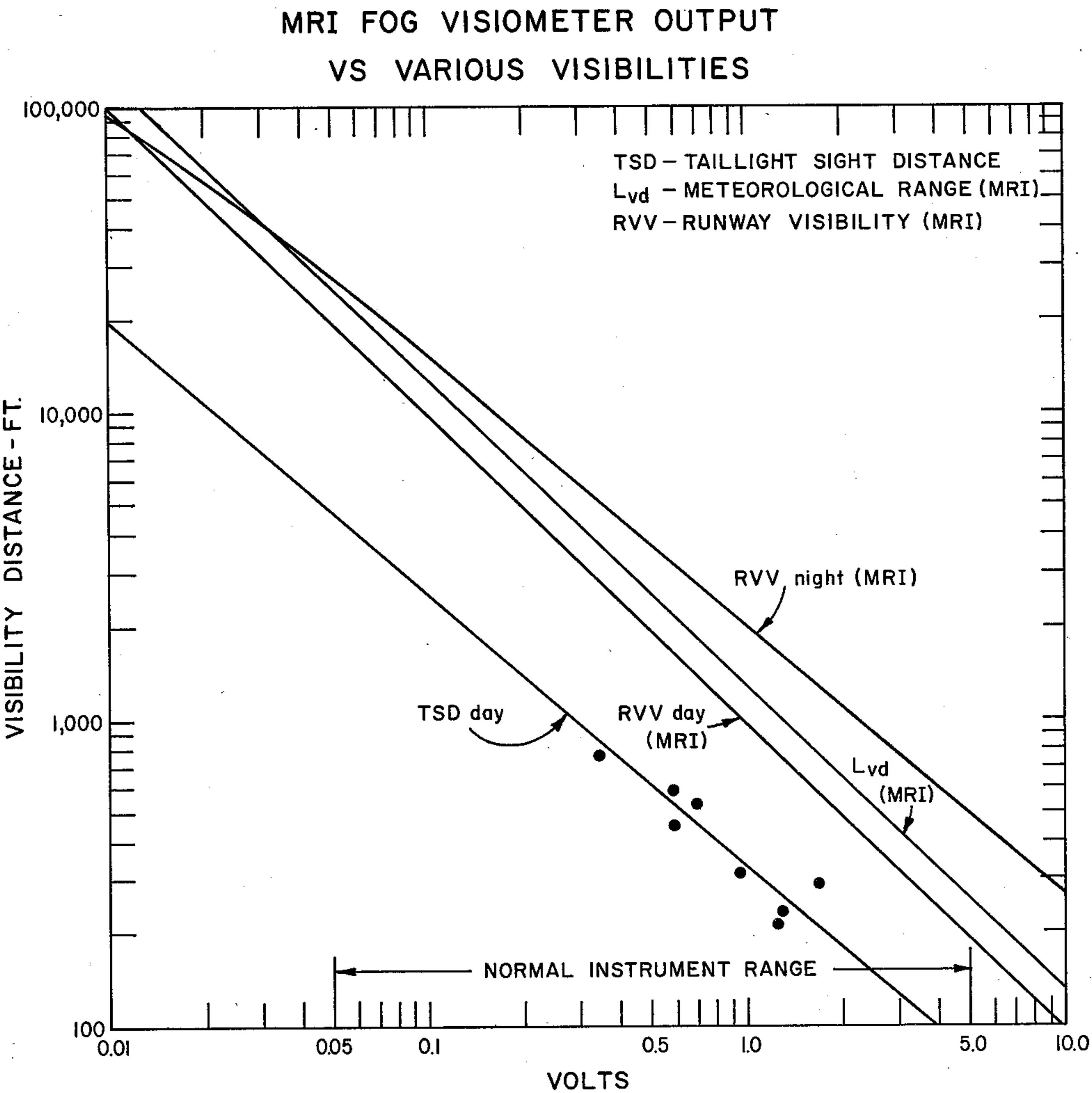


Figure 6
(from Reference 1)

When connected to the sign, the CHP felt that the Fog Visiometer was not turning on the fog sign when it should have been. However, the CHP had probably become accustomed to seeing the sign turn on at 500 feet while connected to Lear Siegler's instrument. The Fog Visiometer was set to turn on the sign when the visibility dropped to 300 feet and turn the sign off when the visibility improved to 450 feet.

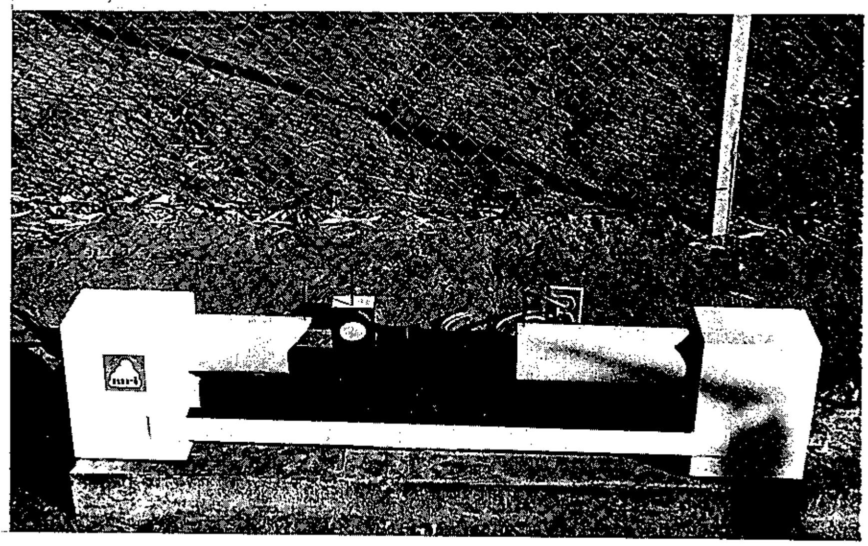


Figure 7

Fog Visiometer before Final Installation on Pole

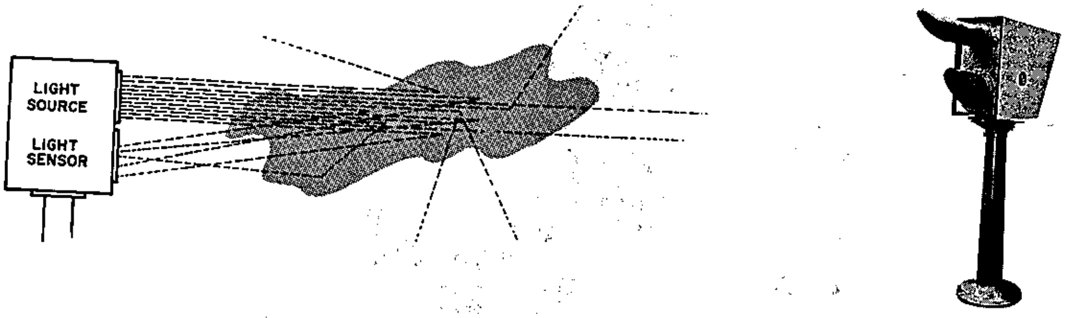
During the period of study, no operational problems were observed. The instrument was operated with proper exposure only for two months.

Kahl Scientific - Videograph

The Videograph as supplied by Kahl Scientific is not applicable for use on the highway. The instrument is able to measure a minimum visibility of .06 mile (316 feet). Readings are obtainable only in increments of about 100 feet (or more) since the instrument is graduated in the nearest 5/100 mile at the lower visibilities. Above 0.20 miles, the graduations are in 1/10 mile increments. The maximum range is 6 miles.

The Videograph is a backscatter device which has both the flash unit and the receiver unit mounted on the same stand. The light that reflects off the fog and back towards the flasher unit is called backscatter light. There is a possibility for backscatter devices to overestimate visibility in a dense fog since absorption losses of light can be significant in this case. Kahl Scientific does not feel that the instrument can be made to function properly below .06 miles[7].

No operational difficulties were encountered. However, the short duration of field exposure (1 month) was not sufficient to demonstrate the instrument's durability



39AM300 VIDEOGRAPH (BACK-SCATTER VISIBILITY MONITORING)

Figure 8

Kahl Scientific Videograph

AeroVironment, Inc. - Highway Fog Monitor

AeroVironment installed a Model 150 Highway Fog Monitor for evaluation. This instrument measures light that is scattered in the forward direction with the direct path of the light blocked by a dark object. The path of the light follows the surface of two cones placed back-to-back with the light scattering from fog in a donut-shaped region where the bases of the cones meet. This donut-shaped region is the sample volume since the geometry of the device only allows light scattered in this region to be sensed at the receiving end.

The light source is near the ground and shines upward a distance of about 4 feet. The instrument flashes the light at a slow rate when the visibility is above 1000 feet and increases the rate of flashing when the visibility drops below 1000 feet.

This instrument was observed to be flashing at the slow rate when the visibility was low (around 250 feet). When notified of this problem, the supplier removed the instrument for servicing and did not return the instrument to the test site. Since this was a prototype instrument, the supplier was not able to replace it with another instrument.

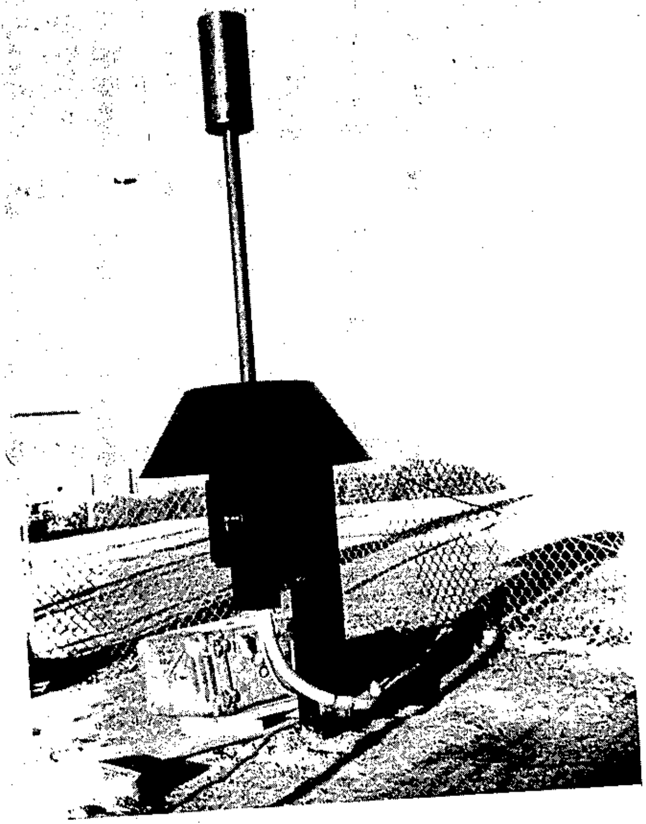


Figure 9

AeroVironment Highway Fog Monitor

Future Studies

It appears that there is a sufficient need for an automatic fog warning system. Much effort has been expended by various agencies in an effort to successfully warn the motorist of unseen dangers. It does not seem feasible at this time to warn the motorist of stopped vehicles (via loop detectors or radar for example). Warning the motorist of reductions in safe driving speed which are beyond his visibility range seems to be the most feasible alternative.

To warn the motorist of changes in driving conditions ahead, it is necessary to have several fog sensing devices. The sensors should be placed in locations that historically experience the most dense fog conditions. Since many automatic fog sensors would be required for this type of system, they must be fairly inexpensive. Extensive field installation would also not be feasible.

Two automatic fog detectors which were not tested, but which may have a great potential are:

1) Closed circuit television - This could be directed towards targets placed at incremental distances along the roadway. A count of the number of targets visible (this could be done electronically) would directly yield the existing visibility. The camera also could be directed towards the traffic to inform the Highway Patrol or Traffic Branch of onroad conditions.

2) Small Sized Backscatter Device - This device would be very small (about 6" to 8" in greatest dimension) and could be inconspicuously mounted on a guard rail post. It would be operated by a dry cell battery and would emit a low energy light. This instrument would be fairly inexpensive and could be installed in greater numbers than larger, more expensive devices. The feasibility of using a large number of devices would offset the relatively small sample volume.

To overcome difficulties encountered during this period of study with regard to relating actual visibility to instrument visibility, time lapse photography could be used to measure the actual visibility. This would insure that all periods of fog were observed, whether it occurred during working days or not. One of the fog sensors could trigger the camera so that it only operated during periods of reduced visibility. The visibility targets could be square, black objects with lights mounted on one corner. They could be spaced out at 50 feet increments and the number of targets visible would indicate the visibility. Care must be taken to insure that the visibility reduction is due to fog and not dirt on the lens or some other interference. Also, a camera and the human eye do not always perceive contrast in a like manner.

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